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IMPULSE DRYING PILOT PRESS DEMONSTRATION: CERAMIC SURFACES INHIBIT DELAMINATION

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Summary

Impulse drying research at the Institute of Paper Science and Technology has concentrated on developing impulse drying process modifications that facilitate impulse drying of heavy weight grades while avoiding sheet delamination. Pilot impulse drying trials conducted with a ceramic coated roll are presented to show that sheet specific surface limits maximum impulse drying temperatures. Corresponding laboratory-scale impulse drying simulations are also presented to show that the ceramic coatings avoid sheet delamination by decoupling heat transfer from overload pressure and the physical state of the sheet. Water removal and energy transfer data are used to estimate energy savings for the process. Based on the results of these studies, the future of impulse drying as an emerging technology is projected.

Introduction

Lavery(1) reported energy measurements made on a laboratory-scale impulse drying simulator. Measurements were made using a lithium tracer technique. The amount of liquid water transferred from the sheet to the felt was calculated from the amount of lithium absorbed by the felt. Lavery assumed that all the water in the sheet was heated to 100°C and that vapor was formed at one atmosphere. Energy transfer was then estimated from an energy balance. Lavery considered this approach to be conservative since much of the water removed was removed from the sheet at temperatures less than 100°C.

Lavery defined "specific energy use" as the energy transferred to sheet divided by the mass of water removed from the sheet. He reported specific energy use for the impulse drying of 127 g/m^2 single-ply linerboard formed from a southern pine refined to 730 ml CSF. In his experiments, handsheets were preheated to 82°C prior to impulsed drying with a steel platen. Dwell times of 15 and 25 ms, temperatures of 200 and 300°C, and peak pressures of 2.8 and 4.8

MPa were run over a range of ingoing solids from 45 to 71%. He found that specific energy use increased with increasing ingoing solids. He reported specific energy use of 1300 kJ/kg at ingoing solids of 45% and 2700 kJ/kg at ingoing solids of 71%. Based on these values, he proposed that impulse drying could be used as a third-press replacement as well as a partial replacement for the dryer section.

In addition, Lavery showed that energy use per square meter of paper increased with increasing peak pressure, increased platen temperature and increased dwell time, and decreased with increasing ingoing solids. For linerboard the correlations showed an increase of 0.15 $kJ/m^2 \cdot °C$ and an increase of 2.09 $kJ/m^2 \cdot MPa$. At the maximum pressure, temperature, and dwell times of his experiments, his correlations yield an energy use of 85 kJ/m^2 at ingoing solids of 45% and 39 kJ/m^2 at 71%.

In subsequent work, Lavery(2) used the lithium tracer technique to expand the range of energy data to lower ingoing solids. In addition, measurements of instantaneous heat flux were obtained by a surface thermocouple technique.

He reported heat flux measurements for the impulse drying of preheated 125 g/m^2 linerboard using a haversine pressure pulse with a peak pressure of 3.4 MPa and a dwell time of 40 ms. The initial platen temperature was 315°C, while ingoing solids were varied from 20 to 50% solids. He found that peak heat flux decreased with increasing ingoing solids. Energy transfer can be determined by integration of the heat flux versus time data. Energy transfer was also found to decrease with increasing ingoing solids. The peak heat flux for linerboard entering at 30 and 40% solids were 3.0 and 2.5 MW/m^2, while energy transfer was 71 and 66 kJ/m^2, respectively.

Recently, Orloff(3) reported a comparison of laboratory-scale impulse drying with platens made from both high and low "thermal mass" materials. "Thermal mass" was defined as the square root of the product of the density, thermal conductivity, and specific heat of the platen surface. The experiments showed that low "thermal mass" ceramic surfaces allow successful operation at higher temperatures and pressures than with high "thermal mass" steel platen surfaces.

An attempt was also made to measure energy transfer by using surface thermocouples. Energy transfer was measured as a function of initial platen temperature and peak pressure for preheated 205 g/m^2 linerboard sheets impulse dryed using a haversine pressure pulse for a dwell time of 20 ms. At a given platen temperature, the energy transferred from the steel platen was much higher than from the ceramic coated platen. Energy transfer increased with increasing pressure for the steel platen, while it was independent of pressure for the case of the ceramic coated platen. This observation was used to explain how ceramic surfaces avoid sheet delamination. For the ceramic coated platens, overload pressure could be increased without increasing the amount of energy transferred to the sheet or the amount of flash evaporation leading to sheet delamination at nip decompression.

At a steel platen initial temperature of 315°C, Orloff measured energy transfer of 45 kJ/m^2 at a peak pressure of 3.1 MPa and 65 kJ/m^2 at a peak pressure of 6.2 MPa. These values can be adjusted to the conditions of Lavery's experiments by assuming that energy transfer is independent of basis weight and is proportional to the square root of dwell time. Therefore, Orloff's data would suggest energy transfer of 66.7 kJ/m^2 at a peak pressure of 3.4 MPa and a dwell time of 40 ms. This is in good agreement with Lavery's value of 71 kJ/m^2.

A major limitation was encountered in the measurement of heat flux for the case of the ceramic coated platen. For those experiments, a 0.064 mm thick iron constantan ribbon thermocouple was used to record the temperature of the interface between the platen and the sheet. It was found that the thermocouple sticks to the sheet during nip decompression leading to a false second heat flux peak. In addition, because of its thickness, the thermocouple itself may have contributed as an energy source. Therefore, the shape of the heat flux curve could not be accurately determined for the ceramic case, and energy transfer measurements were assumed to be upper limits.

To obtain accurate heat flux measurements, Orloff(4) has recently used very thin vacuum deposited surface thermocouples. These thermocouples have the advantage of being an integral part of the ceramic platen surface and have negligible mass. Orloff has used these more accurate heat flux measurements as a boundary condition to a numerical heat transfer model to predict roll heating efficiency. The simulations show that roll durability and heating efficiency are dependent on the internal roll temperature and the choice of roll heating technology. In particular, roll heating efficiencies of 50 to 80% were shown to be possible depending on internal roll temperatures that can be sustained.

In pilot-scale experiments, Orloff(5) confirmed earlier laboratory-scale findings that a low "thermal mass" ceramic roll coating allows impulse drying of heavy weight grades without sheet delamination. The experiments showed that nip residence times of at least 40 ms and ingoing solids of a least 42% were required to obtain dryness in excess of 55%.

Critical roll temperatures were defined as the maximum roll temperature that could be operated without sheet delamination. Orloff's experiments showed that the critical temperature decreased when the specific surface of the ingoing sheet was increased. As cooking, refining, and pressing affect specific surface, the experiments helped to bracket the ranges of these variables that would benefit from impulse drying. In that regard, maximum benefit from impulse drying was predicted for high-yield furnishes that have been minimally refined and pressed to high dryness levels.

The objectives of the work described in this paper were to extend the pilot scale impulse drying trials to the case of a second furnish and to verify the influence of specific surface. An additional objective was to confirm that heat transfer from the ceramic coating to the sheet is independent of overload pressure and to determine if specific surface influences energy transfer. The final objective was to estimate energy savings that can be expected from the process and to identify additional research needs.

Experimental Procedures

Furnish Characterization

Single-ply liner at a basis weight of 205 g/m^2 was made from an unbleached southern softwood kraft bottom sheet linerboard pulp collected from the last stage washers. Pulp from two mills was used in the experiments. Pulp from the first mill was received in two batches, the first batch having a Kappa number of 74 while the second batch at a Kappa number of 65. Pulp from the second mill was received in a single batch at a Kappa number of 98. Once received from the mill, the pulp was washed to remove residual black liquor and refined on a 2.3 kg Valley beater to the desired freeness. To get ingoing solids of 42%, the linerboard was formed on the IPST slow-speed web former, unwound, and pressed on the second nip of the pilot dryer. To characterize the rolls of pressed paper, fiber length distributions were measured by the projection method, and fiber width, perimeter, and coarseness were also measured. In addition, the out-of-plane permeability (5) was measured as a function of sheet porosity to determine specific surface as shown in Figures 1 and 2.

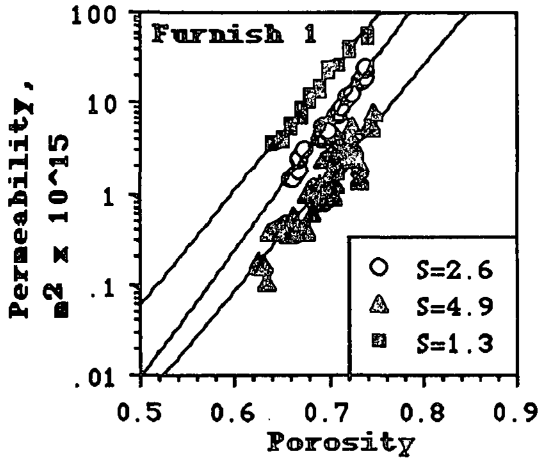

Figure 1.
Out-Of-Plane Permeability
Versus Porosity For
Furnish 1 At 42% Dryness.

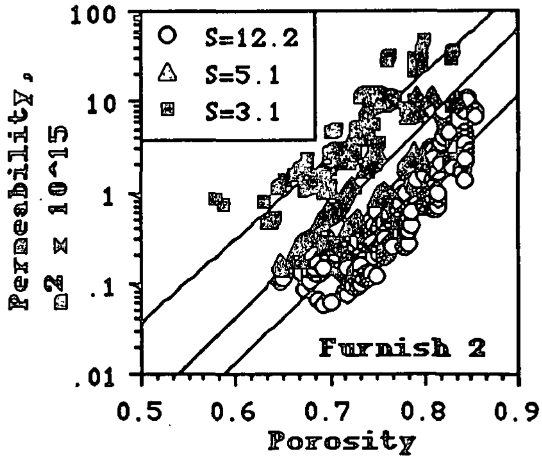

Figure 2.
Out-Of-Plane Permeability
Versus Porosity For
Furnish 2 At 42% Dryness.

Average sheet characteristics are shown in Table 1, while corresponding species identifications are given in Table 2.

Table 1. Fiber And Sheet Characteristics.

Furnish Number	Freeness ml CSF	Kappa Number	Length WWtdMean mm	Width micron	Perimeter micron	Coarseness mg/100m	Specific Surface m^2/g
1	650	74	2.00	NA	NA	NA	1.3
1	550	65	2.69	36.7	85.0	33.8	2.6
1	650	65	2.79	35.8	83.6	34.2	4.9
2	550	98	3.09	35.7	82.9	32.4	12.2
2	650	98	2.65	37.3	86.5	30.7	5.1
2	740	98	2.48	37.8	88.5	33.4	3.1

Table 2. Species Identification.

Furnish Number	USWK %	UHWK %	Softwood Species	Hardwood Species
1	100-	trace	Southern Yellow Pine hard cook, small % soft cook	Gum, Oak
2	95+	5	Southern Yellow Pine hard cook	Gum, Oak, Yellow Poplar

The Pilot Impulse Dryer

A schematic of the pilot impulse dryer is shown in Figure 3. The internal structure of the plasma sprayed ceramic roll coating has been described previously (3-5). The ceramic coating had an effective "thermal mass" of 2000 $W \cdot s^{1/2}/m^2 \cdot {}^\circ C$. The roll was heated by an external source of infrared radiation as controlled by an infrared sensor. The sensor was positioned just prior to the nip (within 0.38 m) to record the temperature of the roll and to serve as the input to the temperature controller. The controller adjusted the output of the infrared roll heaters to maintain a constant ingoing roll surface temperature.

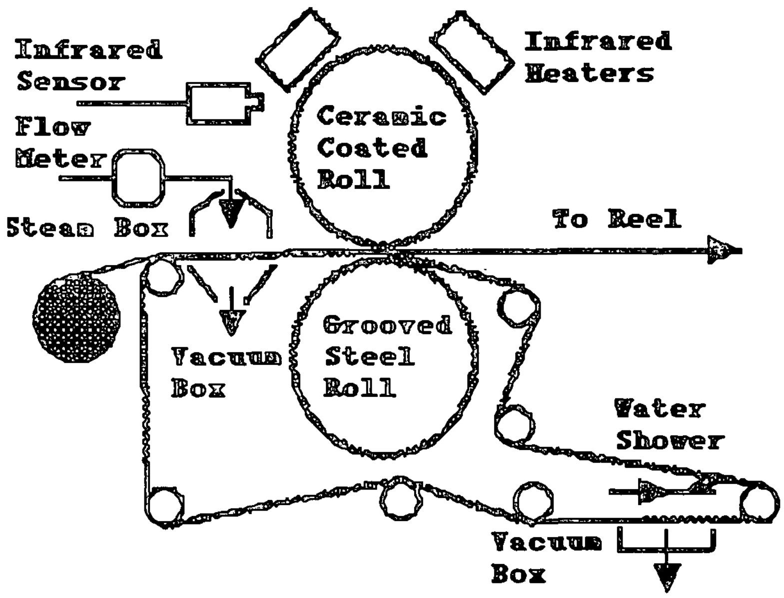

Figure 3. Schematic Of The Pilot Impulse Dryer.

Sheet preheat temperature was adjusted using a steam box in combination with a vacuum box. The steam preheating system was calibrated (5) for each change in furnish and refining level to control ingoing sheet temperature between 90 and 100°C and to account for water addition to the sheet.

Felts used in the experiments were constructed of a nylon base and a Nomex working surface. The felt was conditioned by spraying water on both of its sides and removing excess water with a vacuum. This washed and cooled the felt and provided a consistent felt moisture ratio of 0.15 to 0.20.

In the experiments, the nip was set and balanced to a peak pressure of 6.2 MPa as verified using Fuji prescale LW pressure-sensitive film. Based on a measured nip width of 20 mm at 6.2 MPa, a dryer speed of 30 m/min corresponded to a dwell time of 40 ms.

To show the benefit of impulse drying over single-felted wet pressing, impulse drying experiments were conducted over a range of ingoing roll surface temperatures from 100°C to 430°C. To prevent the web from sticking to the heated roll at low temperatures, a polymeric release agent was applied to the ceramic roll.

After obtaining the appropriate dryness, paper made on the web former was placed on the unwind stand of the pilot impulse dryer. Paper was then threaded into the pilot impulse dryer at 6 m/min with the nip open. After threading the nip was closed, and the steam and vacuum were turned on. Once the paper was threaded onto the reel, the controller would uniformly and quickly bring the machine up to the desired speed and hold that speed until the conclusion of the run.

The experimental objective was to compare the performance of the prototype ceramic coated press roll for two different virgin southern pine kraft furnishes. The key performance parameters were, water removal, property development, and avoidance of sheet delamination. To characterize the physical properties of the paper, samples of the impulse dried paper were finish dried on a drum dryer, conditioned to TAPPI standards, and tested. As previously discussed(5), 60 locations per sheet were tested by out-of-plane ultrasound and by STFI compression tests, while three locations per sheet were tested for burst strength. In addition, samples from each condition were also frozen in liquid nitrogen, fractured, and cross sections analyzed using a scanning electron microscope.

Sheet delamination was detected by a three-step process. At the first step, the micrographs were examined to search out samples showing visible delamination. This procedure tended to identify clear instances of delamination resulting from impulse drying at extreme roll surface temperatures. The second step consisted of examining the measured average strength properties as a function of roll surface temperature. Sheet delamination was identified when an increase in roll temperature resulted in a decrease in an average strength property. The third step examined the coefficient of variation of the specific elastic modulus. Delaminated regions of a sheet exhibit lower out-of-plane specific elastic modulus than surrounding nondelaminated regions of the sheet. Therefore, the coefficient of variation of the out-of-plane specific elastic modulus was helpful in detecting delamination in cases where small discrete delamination spots occurred.

Measurement Of Heat Flux

Figure 4 shows a schematic of the electrohydraulic press used to simulate impulse drying and to measure heat flux.

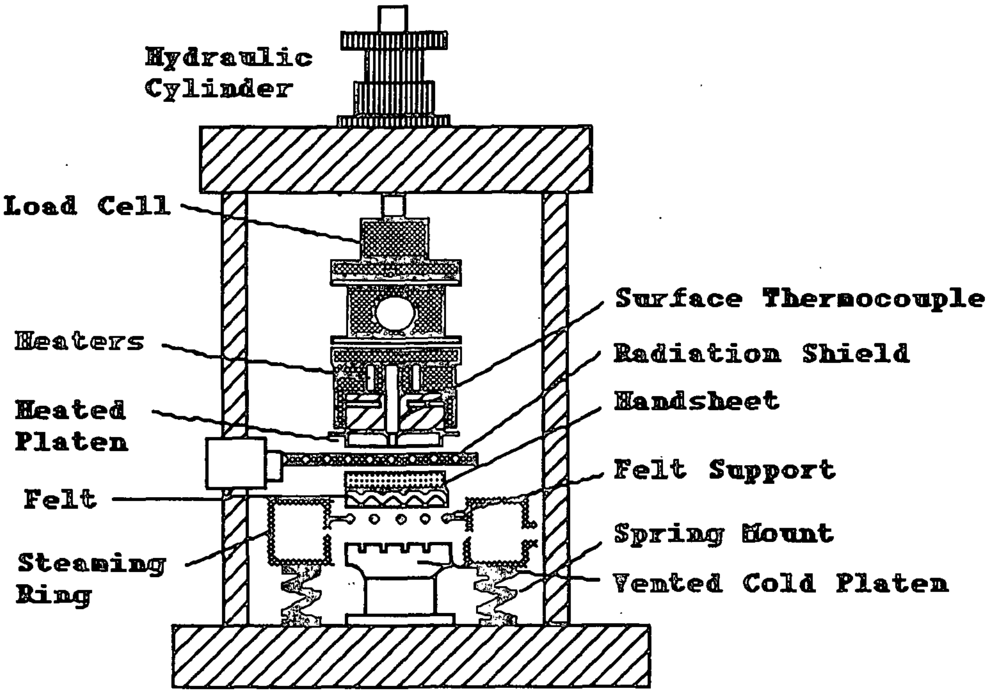

Figure 4. Schematic Of The Electrohydraulic Press.

Wet sheets, sampled from the inlet to the pilot steam box, were placed on felts on a wire support attached to a steaming ring. During steam preheating, a radiation shield was used to reduce dry-out of the top surface of the sheet. Steam exiting the ring flowed upward through the felt and the sheet. By controlling steam pressure and adjusting the steaming time, the initial temperature in the sheet was raised to 85°C.

Once the sheet was heated, the hydraulic system was activated to give a haversine pressure pulse of 40 ms duration at a specified peak pressure. The temperature at the surface of the ceramic platen was recorded by a specially designed vacuum deposited thermocouple during the impulse drying event. As the structure and thermal properties of the ceramic coating were known, heat flux to the paper sheet could be calculated as a function of time (4). Integrating heat flux over the duration of the impulse yielded energy transfer.

To prove that peak pressure can be increased without affecting energy transfer, samples of sheets made from Furnish 1 at specific surfaces of 1.3 and 2.6 m^2/g were impulse dryed at both 3.1 and 6.2 MPa peak pressures over a range of ingoing platen surface temperatures. Figure 5 shows that energy transfer was linearly dependent on ingoing temperature and was independent of both peak pressure and specific surface.

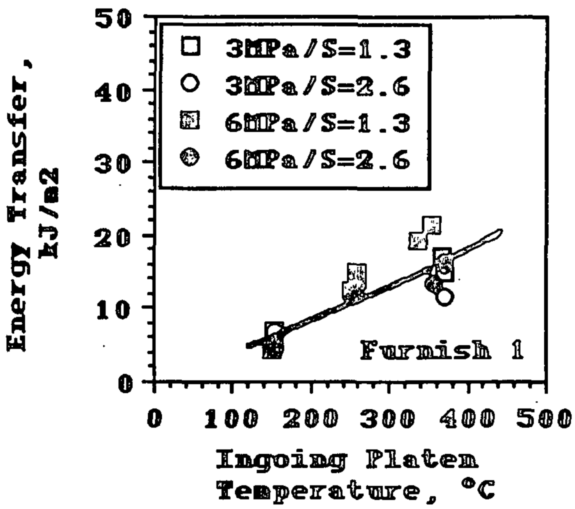

Figure 5.
Energy Transfer Versus
Ingoing Platen Temperature
For Furnish 1 At 3.1 And 6.2 MPa
Peak Pressure.

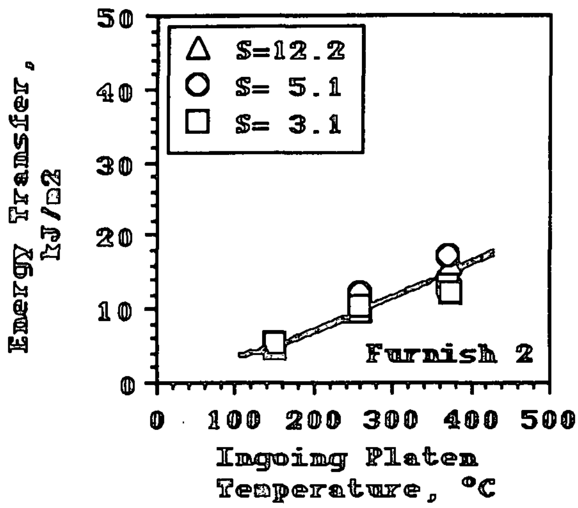

Figure 6.
Energy Transfer Versus
Ingoing Platen Temperature
For Furnish 2 At 6.2 MPa
Peak pressure.

Similarly, sheets made from Furnish 2, having specific surfaces of 3.1, 5.1, and 12.2 m^2/g were impulse dryed at a peak pressure of 6.2 MPa to match pilot experiments. Figure 6 again shows that energy transfer was linearly dependent on ingoing platen temperature and independent of specific surface. In addition, there was no statistically significant difference in energy transfer between the two furnishes.

Discussion Of Pilot-Scale Results

Water removal and physical property data from pilot experiments with the first furnish have been described elsewhere(5). Table 3 and 4 summarize those findings in terms of the performance at the critical temperature and at a reference roll temperature of 106°C.

Table 3. Impulse Drying At The Critical Temperature. (Furnish 1)

Specific Surface m^2/g	Critical Temp. °C	Outgoing Solids %	IPC Density g/cc	Specific Elastic Modulus MN·m/kg	Burst Index kPa·m^2/g	Geometric Mean STFI Index N·m/g
1.3	371	59.6	0.79	0.13	3.9	23.8
2.6	316	58.7	0.80	0.17	3.7	24.9
4.9	204	50.7	0.76	0.16	4.0	28.2

Table 4. Impulse Drying At A Reference Temperature.
(Furnish 1)

Specific Surface m^2/g	Reference Temp °C	Outgoing Solids %	IPC Density g/cc	Specific Elastic Modulus MN·m/kg	Burst Index kPa·m^2/g	Geometric Mean STFI Index N·m/g
1.3	106	53.7	0.68	0.08	3.0	21.3
2.6	106	50.9	0.72	0.11	2.4	24.3
4.9	106	48.0	0.75	0.15	3.0	28.2

The pilot-scale results for the second furnish are reviewed in more detail. Rolls of paper made from Furnish 2 were preheated to 100°C at an ingoing dryness of 42% before being impulse dryed at a peak pressure of 6.2 MPa and residence time of 40 ms. Figure 7 shows outgoing solids as a function of ingoing roll surface temperature and specific surface. As expected minimizing specific surface by reduced refining resulted in higher outgoing solids at all ingoing roll surface temperatures.

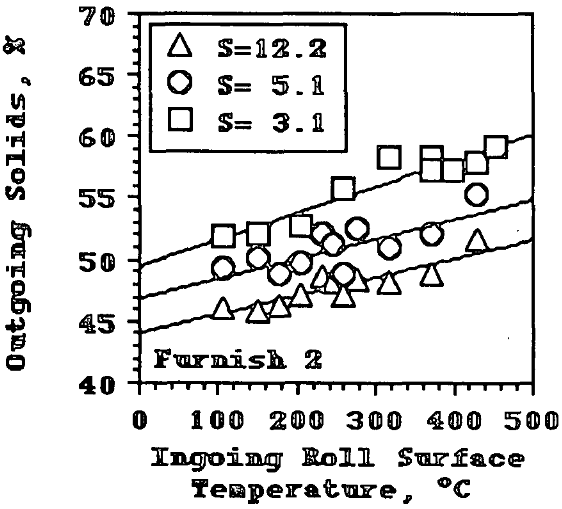

Figure 7.
Outgoing Solids Versus Ingoing Roll Surface Temperature For Furnish 2 At 6.2 MPa Peak Pressure For 40 ms .

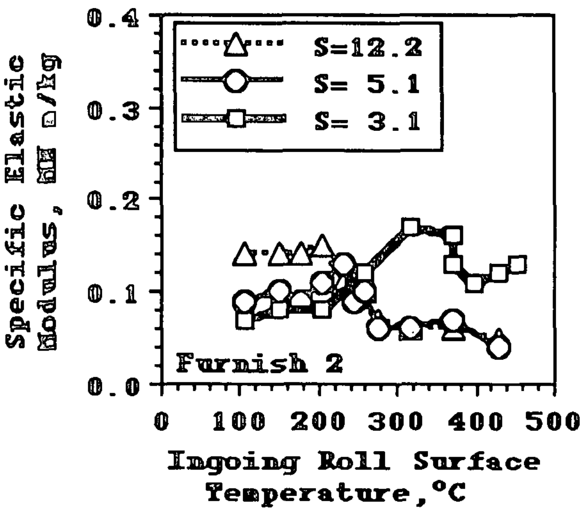

Figure 8.
Out-Of-Plane Specific Elastic Modulus Versus Ingoing Roll Surface Temperature For Furnish 2 At 6.2 MPa Peak Pressure For 40 ms.

To find the critical temperatures for each case, physical property data were plotted as shown in Figures 8 through 11. The out-of-plane specific elastic modulus is shown as a function of ingoing roll surface temperature in Figure 8. As was previously observed (5), the roll surface temperature corresponding to the drop-off in elastic modulus increased with decreasing specific surface.

The sheet average coefficient of variation of the specific elastic modulus is shown on Figure 9. High variability, characteristic of sheet delamination, begins to occur at higher roll temperatures as the specific surface was decreased. This is consistent with Figure 8 and with previous results.

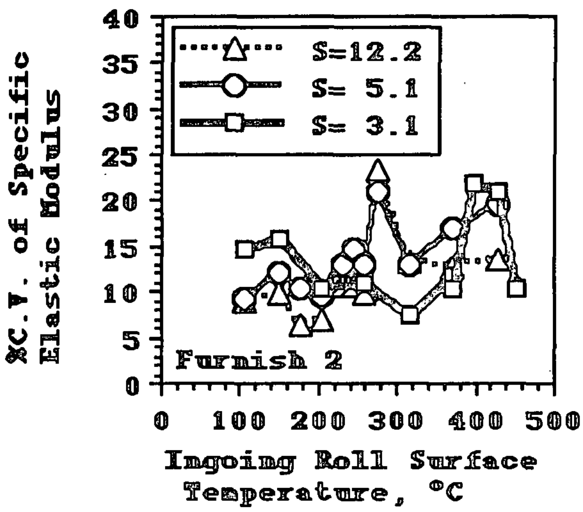

Figure 9.
C.V. Of Out-Of-Plane Specific Elastic Modulus Versus Ingoing Roll Surface Temperature For Furnish 2 At 6.2 MPa Peak Pressure For 40 ms.

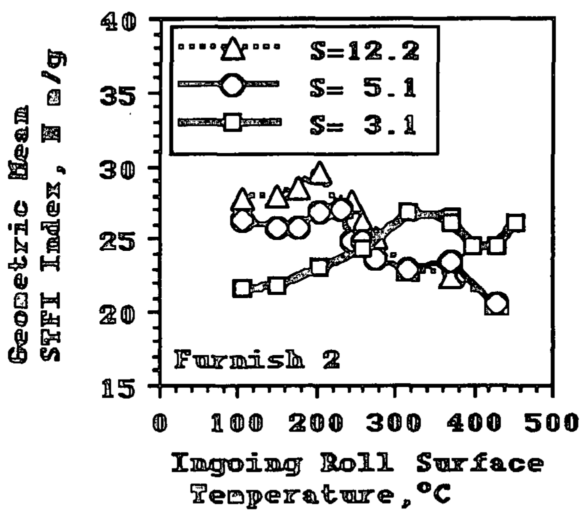

Figure 10.
Geom. Mean STFI Compression Index Versus Ingoing Roll Surface Temperature For Furnish 2 At 6.2 MPa Peak Pressure For 40 ms.

The geometric mean STFI Compression Index is shown as a function of ingoing roll surface temperature in Figure 10. These results are also consistent with Figure 8. As the STFI Index is an important physical property it is of interest to observe the substantial improvement of STFI index for minimally refined sheets.

For completeness burst index is also presented in Figure 11.

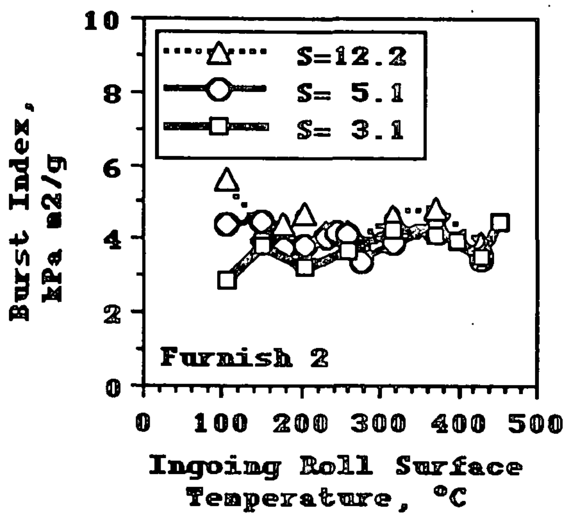

Figure 11.
Burst Index Versus Ingoing Roll Surface Temperature For Furnish 2 At 6.2 MPa Peak Pressure For 40 ms.

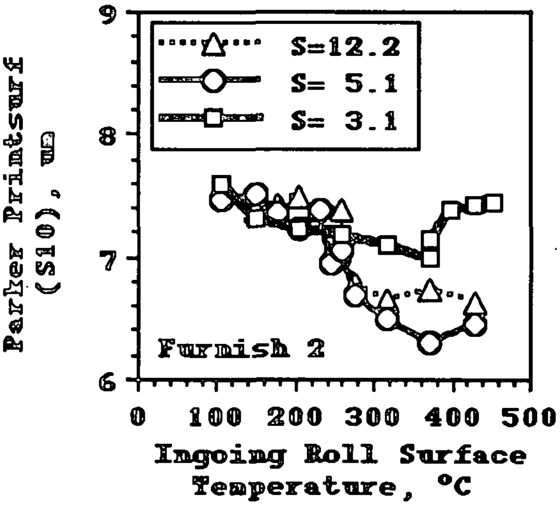

Figure 12.
Parker Printsurf (S10) Versus Ingoing Roll Surface Temperature For Furnish 2 At 6.2 MPa Peak Pressure For 40 ms.

Impulse drying typically results in improved smoothness on the side of the paper contacting the heated roll. To quantify that effect, Parker Printsurf was used to measure the smoothness of the side of the sheet in contact with the roll as a function of ingoing roll surface temperature. As shown in Figure 12, increasing the roll temperature increases the smoothness of the sheet.

Critical temperatures were determined based on the data presented in Figures 8 through 11. A summary of the critical temperatures and corresponding physical properties are shown in Table 5. A summary of physical properties at the reference temperature of 106°C and for control sheets that were finish dryed from 42% solids without impulse drying are shown in Table 6.

Table 5. Summary Of Results At The Critical Temperature. (Furnish 2)

Specific Surface m^2/g	Critical Temp °C	Outgoing Solids %	IPC Density g/cc	Specific Elastic Modulus MN·m/kg	Burst Index kPa·m^2/g	Geometric Mean STFI Index N·m/g
12.2	204	47.2	0.73	0.15	4.7	29.6
5.1	232	52.0	0.75	0.13	4.0	27.1
3.1	316	58.4	0.77	0.17	4.3	26.8

Table 6. Summary Of Results At The 106°C Reference Temperature And For An Unpressed Control. (Furnish 2)

Specific Surface m^2/g	Roll Temp °C	Outgoing Solids %	IPC Density g/cc	Specific Elastic Modulus MN·m/kg	Burst Index kPa·m^2/g	Geometric Mean STFI Index N·m/g
12.2	106	46.1	0.72	0.14	5.6	27.8
5.1	106	49.3	0.69	0.09	4.4	26.3
3.1	106	51.8	0.63	0.07	2.9	21.7
12.2	NA	(42)	0.60	0.11	4.05	25.8
5.1	NA	(42)	0.57	0.08	4.62	25.2
3.1	NA	(42)	0.40	0.03	1.73	15.0

The relative improvement in physical properties and drying energy efficiency achieved by impulse drying depends on the basis of comparison. Data obtained at a reference temperature of 106°C should correspond to the maximum water removal and physical property development that can be obtained at that impulse through single-felted extended nip pressing.

A 23% improvement in STFI compression strength was achieved at a specific surface of 3.1 m^2/g corresponding to a freeness of 740 ml CSF, while an improvement of 6% was achieved at a specific surface of 12.2 m^2/g corresponding to a freeness of 550 ml CSF.

The critical impulse drying temperature and corresponding outgoing solids for both furnishes, are shown in Figures 13 and 14. It is observed that maximum outgoing solids occur when the specific surface is minimized and that the two furnishes performed similarly.

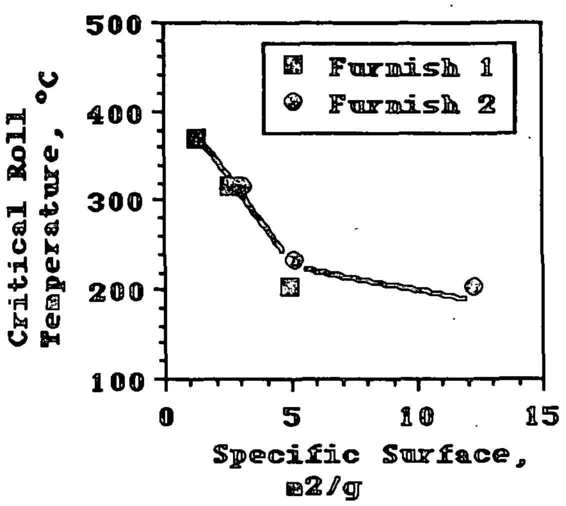

Figure 13.
Critical Ingoing Roll Surface Temperature Versus Specific Surface For Furnishes 1 And 2.

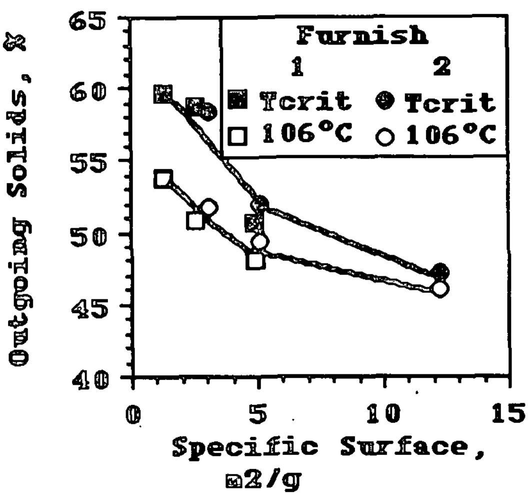

Figure 14.
Outgoing Solids At The Critical Temperatures And At A 106°C Reference Temperature Versus Specific Surface For Furnishes 1 And 2.

Energy Calculations

At a given ingoing surface temperature and impulse, the low "thermal mass" ceramic coated surface yields the same water removal as a high "thermal mass" steel surface(3). However, the surfaces differ in the amount of energy that they transfer to the sheet and in the fact that heat transfer from the ceramic surface is pressure independent. At temperatures typically used in impulse drying and depending on pressure, the ceramic surface transfers between one-half to one-third the energy that would have been transferred by a steel surface. As a result, the ceramic surface can be operated at higher pressures and higher temperatures without overheating the sheet and causing sheet delamination. An additional benefit is that the ceramic surface substantially reduces the energy used in the impulse drying process. One way to show this is to compare the specific energy use for ceramic surfaces to that previously reported for steel surfaces. Based on our data, specific energy use ranged from 115 kJ/kg at a specific surface of 1.3 m^2/g to 160 kJ/kg at a specific surface of 12.2 m^2/g. In comparison, Lavery reported specific energy use that was a order of magnitude higher. While some of that difference is due to the conservative nature of the lithium tracer method, much of the improvement is due to the substantial reduction in energy transfer to the sheet.

While specific energy use is useful in comparing the performance of roll surfaces, energy savings are best presented in terms of the energy saved in kW·h per metric ton of paper produced. Our energy calculations are conservative in that they do not credit the process for energy savings due to reduced need for refining or for energy savings due to potential fiber substitutions or basis weight reductions, both of which may be substantial. In terms of potential energy savings, the key elements of the calculation are the amount of energy transferred to the sheet during the impulse, the energy efficiency of the roll, and the basis of comparison.

The calculations were performed for the case of a 205 g/m^2 single-ply linerboard impulse dryed from 42% solids. Specific surface was assumed to be 1.5 m^2/g to match the ideal situation of a minimally refined sheet. At a roll temperature of 360°C, such a sheet could be impulse dryed to 60% solids. Energy transfer to the sheet was taken from the experimental measurements as 17 kJ/m^2. Roll heating efficiency was estimated from previous numerical simulations based on external radiant heating and three levels of internal roll temperature. Roll heating efficiencies of 50%, 60%, and 70% corresponded to internal temperatures of 150°C, 200°C, and 250°C.

Paper machine builders generally report outgoing solids of 52% from pilot-scale long nip presses. Once installed on a commercial paper machine, long nip presses would be expected to deliver between 48 to 50% outgoing solids. As the comparison reference process is also important, we have performed the calculation over a range of values from 46% to represent standard practice to 54% to represent double-felted extended nip pressing.

Energy savings were calculated as the energy content of steam that does not have to be used to heat conventional cylinder dryers minus the energy content of the fuel used to produce the electric power required by the impulse dryer. It was assumed that 1.5 kg of cylinder dryer steam are required per kilogram of water evaporated by the cylinder dryer. The cost of steam was taken as 7.16US$/metric ton of steam. While the roll can be heated by various means, the present calculations have assumed an electrical energy source. The production and distribution of electricity were assumed to be 30% efficient.

Figure 15 shows that energy savings of about 350 kWh/metric tons of paper can be saved over conventional drying. Comparing impulse drying to double-felted extended nip pressing, which is the best alternate technology, energy savings of at least 50 kWh/metric ton could be realized. Figure 15 also shows that while high internal roll temperatures are to be encouraged, significant energy savings can be realized at even low internal temperatures corresponding to roll heating efficiencies of only 50%.

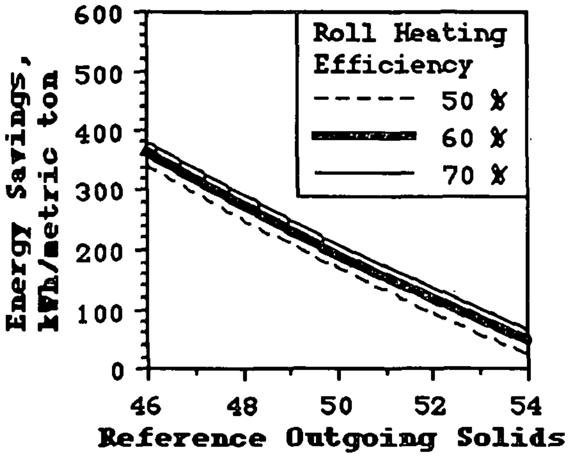

Figure 15.
Energy Savings Versus Reference Outgoing Solids And Roll Internal Temperature.

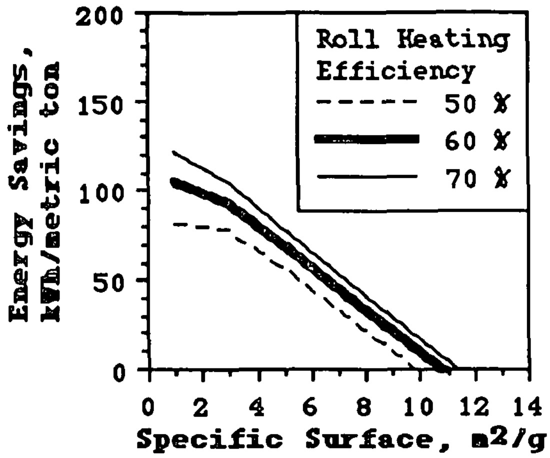

Figure 16.
Energy Savings Resulting From Impulse Drying At The Critical Temperature As Referenced To Impulse Drying At 106°C.

Figure 16 shows the results of a similar calculation in which the reference process was taken as single-felted extended nip pressing as predicted by our impulse drying experiments at 106°C reference temperature. In the calculations, the critical impulse drying temperature was chosen at each value of specific surface. The figure shows that relative to single-felted extended nip pressing, energy savings can be realized up to a specific surface of about 10 m^2/g.

In Figure 17, the results of Figure 15 are expressed as a production cost savings in units of US dollars per metric ton of paper produced. Clearly, the cost savings depends on the cost of electric power to heat the roll and to a lesser extent on the efficiency of roll heating. In the United States, the cost of on-site electric power production would be calculated as the cogeneration fuel cost ranging from 0.01 to 0.02 US$/kWh. Therefore, compared to conventional drying, energy cost savings of about 4.50 US$/metric ton could be realized, while 1.50 US$/metric ton could be saved compared to double-felted extended nip pressing.

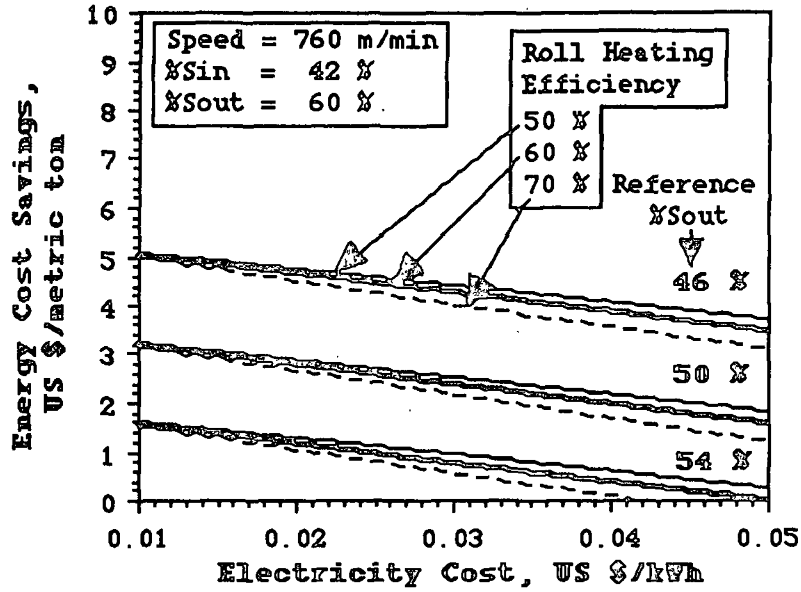

Figure 17.
Energy Cost Savings As A Function Of Electricity Cost And Roll Heating Efficiency For Various Reference Pressing Processes.

Conclusions

Direction Of Future Research

Our pilot-scale experiments have shown that the ceramic coated roll can be used to impulse dry heavy weight grades to high levels of dryness without inducing sheet delamination. Studies using a second furnish confirmed that the specific surface of the sheet controls critical impulse drying temperature and matched the results obtained with an earlier furnish.

Best performance in terms of dryness and property development was exhibited when the specific surface was reduced by limiting the extent of refining. Energy calculations further demonstrated that maximum improvements in energy efficiency will be achieved as the specific surface is reduced.

Previous research (5) has shown that specific surface can be reduced by pressing the sheet to higher levels of dryness prior to impulse drying. Based on Lavery's work it is expected that by impulse drying sheets of higher ingoing solids further improvements to outgoing solids will occur. As energy savings are closely tied to outgoing solids, there is good reason to expect that higher ingoing solids will lead to additional energy savings. In this regard, pilot-scale experiments with sheets of higher ingoing solids are planned for the near future.

From Lavery's experiments (1,2), there is great potential for using impulse drying to enhance the strength of sheets made from recycled fiber. Increasingly, recycled fibers are used in the manufacture of multi-ply liner. Preliminary results suggest that recycled furnishes tend to have high specific surface. Work is currently under way at the Institute to determine the range of variables that influence the specific surface of such sheets and to determine the corresponding critical impulse drying temperatures, property development and energy savings. Work to further reduce the "thermal mass of the ceramic coating is also underway.

In addition, a number of process issues can only be addressed on an extended nip press. In particular, impulse drying with a ceramic coated roll needs to be compared to single- and double-felted pressing on the same apparatus. Such an evaluation performed on a pilot extended nip press would allow optimization of the pressure vs. time curve generated in the extended nip and evaluation at commercial speeds. Such an experiment is now being planned by the Institute in conjunction with the Beloit Corporation through a grant from the U.S. Department of Energy.

If these key experiments are successful, commercialization of the technology will be undertaken by a consortium composed of the Institute, its member companies, machine vendors, and the U.S. Department of Energy.

<u>The Future Of Impulse Drying As An Emerging Technology</u>

The key to the impulse drying concept is to control the flow of heat into the sheet to produce high-pressure steam that displaces water while minimizing the energy available for sheet delamination. Since it takes a large amount of energy to evaporate liquid water (2258 kJ/kg), substantial amounts of energy can be saved by displacing water as a liquid. For the manufacturer of linerboard, the amount of energy reduction from current processes is estimated at 35%, a savings of 350 kW·h/metric ton (1.1 million BTU/ton) of paper. Adding to this already substantial energy savings, impulse drying may also allow the use of energy-efficient, high-yield pulps that are now in limited use due to their inferior strength. Collateral energy savings associated with the use of high yield pulps could actually surpass the direct energy savings from the impulse drying process itself. The prospects of this new process look very promising.

The development of impulse drying is leading edge technology that can heavily impact energy reduction and the weight, cost, and properties of various grades of paper. The impulse dryer is designed in a modular concept that can be retrofitted to existing extended nip presses. Once successful, it most probably can reduce the size of the conventional paper machine by as much as a third. In addition, impulse drying is a technology that can minimize waste by producing better quality paper and board from recycled furnish.

Mechanical pulping provides higher yield pulps and this combined with impulse drying could provide a double dividend in energy savings.

The current work provides information needed to lead successfully into full scale commercialization. A leading U.S. equipment manufacturer, Beloit, has become involved in the current final research stages of the program. Commercialization could take two to three years, depending on funding commitments, allocations and baring minimal problems.

The first implementation of impulse drying will probably be on a linerboard machine because the wide nip press technology which forms the basis for impulse drying is already widely accepted in linerboard mills.

Following success on the linerboard machine, employment on lightweight coated and newsprint machines could follow shortly thereafter. The decision to commercialize and the paths chosen will be determined by various elements of the paper industry. These paths will be determined by production, product quality, economics and competitiveness. The future looks promising.

Once commercialized, impulse drying can potentially save a conservative $6x10^{+10}$ kW·h (0.2 QUADS) of energy annually in the United States. Associated capital and operating cost reductions will help maintain the competitiveness of the U.S.paper industry. Thus, one could venture to say that by the year 1997-98 impulse drying should be within various mills throughout the United States, other parts of North America and perhaps Europe.

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Acknowledgements

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